RESEARCH DEPARTMENT

The visibility of small luminance perturbations in television displays

REPORT No. T-106

1963/18

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

THE VISIBILITY OF SMALL LUMINANCE PERTURBATIONS IN TELEVISION DISPLAYS

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SUMMARY

Measurements of the visibility of small-magnitude luminance perturbations at various parts of the grey scale have been carried out using television displays.* The purpose was to establish whether the measurements carried out by many workers using optical apparatus could be applied to a television screen used in normal viewing conditions. It was found that, in general, very close agreement was obtained. However, the visibility of random noise added to a television picture was found to be appreciably different from that of more coherent luminance changes. The visibility of the noise as a function of the luminance of that part of the display being observed is very much affected by the different retentivity of the human optical system at different values of luminance. It was observed that noise variations are relatively less visible in dark areas of the picture than in bright areas.

1. INTRODUCTION

In television engineering it is of importance to know how the magnitude of a small luminance perturbation must vary with the mean luminance of its background for its visibility to remain constant. Knowledge of this relationship, is, for example, essential if any attempt to compress the channel capacity requirements of a television signal is to be evaluated. A process common to many bandwidth compression proposals is the quantization of the luminance of the picture into a limited number of discrete levels. In order that the number of levels used shall be the minimum consistent with avoiding obvious discontinuities of the grey scale, the size of each quantum of luminance must be related to the visibility of luminance change at that particular luminance level.

Measurements of the fractional luminance-difference for threshold visibility (known as the Fechner fraction) have been made by a number of workers,[1,2] and although these did not involve the use of television displays and were not carried out in illumination conditions typical of television reception, the results have often been assumed to be applicable to television.[3] They lead to the conclusion that, except in the darkest parts of the pictures, the Fechner fraction is almost constant.

On the assumption that this conclusion can be extended to levels of visibility above the threshold, and that video voltage is related to picture luminance by a simple power law, a constant *fractional* change of video voltage may therefore be

* This report includes, in a revised and condensed form, material already published in Research Department Reports T-083 and T-092, as well as the results of further work carried out since these reports were written.

expected to produce constant visibility. However it has been stated,[4] and it is widely accepted, that when a video signal is accompanied by noise, causing the same *absolute* fluctuation of video voltage at all parts of the grey scale, the noise is equally visible in all but the darkest areas. These two statements can be reconciled only on the assumption that the results of optical experiments are inapplicable to television, or that the perception of noise is in some way anomalous.

In order to resolve this situation the series of tests described in this report was undertaken.

2. DESCRIPTION OF EXPERIMENTS

2.1. Threshold of Detail Recognition

This measurement was thought to be useful in determining the optimum number of levels required for a quantized-luminance system. The output signals from two 405-line television picture sources were added and displayed on a 21 in (53 cm) monitor. One source produced "Test Card C" and the other produced a signal corresponding to one of a series of small numerals; the numeral could be superimposed in any one of the squares forming the luminance step-wedge of the test card. For purposes of illustration, Fig. 1 shows a numeral added to each of the five squares, although the tests were made with a numeral displayed in only one square at a time.

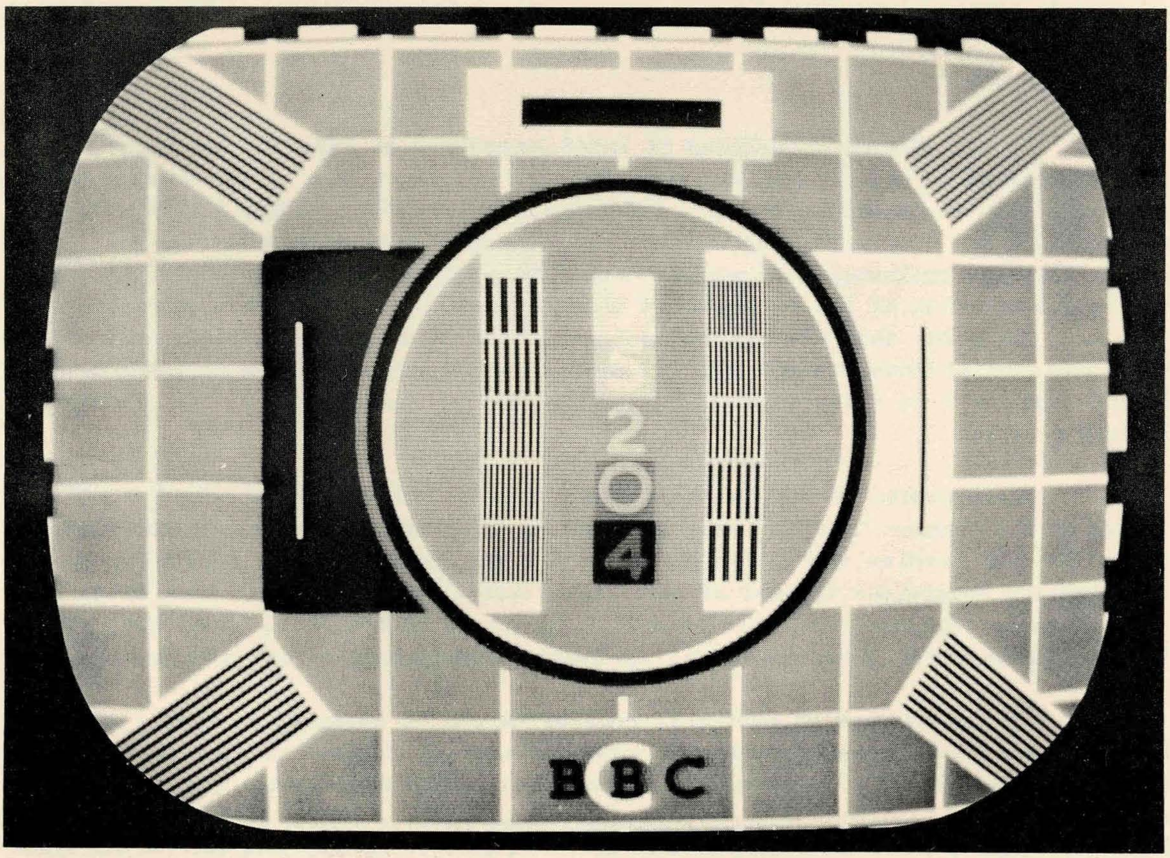

Fig. 1 - Test Card with numerals superimposed

By changing the polarity of its waveform the numeral could be made lighter or darker than the surrounding square. Thirty observers, in groups of five at a time, were seated in front of the television picture-monitor at a distance of between five and seven times the picture height, and were told which square to look at. A numeral was then displayed in that square for a period of one second and the observers were asked to write down the numeral; this procedure was repeated, with different numerals, in a random sequence and at various amplitudes of the "numeral" signal. The test was then repeated for the other squares in the luminance step wedge, the proportion of observers identifying the numeral correctly being recorded for each presentation. In all the experiments the test card was displayed continuously so that adaptation conditions were not changed during the tests.

For the purposes of this investigation it has been found convenient to describe points on the grey scale in terms of a percentage scale of video-signal voltage, zero corresponding to blanking level and 100 per cent representing white; the quantity so defined will be referred to as the picture-signal level.

The ambient lighting was such that, in the absence of phosphor excitation, the luminance of the monitor screen was about 0·15 ft-L (1·6 asb); a white card held in front of the monitor screen had a luminance of about 0·35 ft-L (3·8 asb). The monitor brightness and contrast controls were adjusted so that no raster lines were visible in the large black areas of the test card. In these areas the screen luminance was 0·25 ft-L (2·7 asb), the difference between this value and that obtained when the monitor was switched off, 0·15 ft-L (1·6 asb), being caused, apparently, by flare in the cathode-ray tube face plate; there was no protective glass between the cathode-ray tube and the observers during these tests. The luminance measurements were made with an S.E.I. photometer having a black tube extending from the instrument lens to that part of the monitor screen being examined; this was arranged in order to minimize flare introduced in the photometer lens system. Table 1 shows the luminance of each of the squares in the step-wedge of the displayed test card.

TABLE 1

Description	Luminance	
	ft-L	asb
white square	20	210
light-grey square	12	130
mid-grey square	5	54
dark-grey square	3	32
darkest-grey square	0·3	3·2
large area black square	0·25	2·7

Fig. 2 shows the fractional luminance-differences at which the numerals were correctly recognized in 50 per cent of attempts, plotted as a function of the normalized luminance of the immediate surround (that is, the luminance of the squares in the step-wedge). It will be seen that the fractional luminance-difference $\Delta B/B$ is sensibly uniform over the range from maximum luminance to about 5% of maximum luminance. The

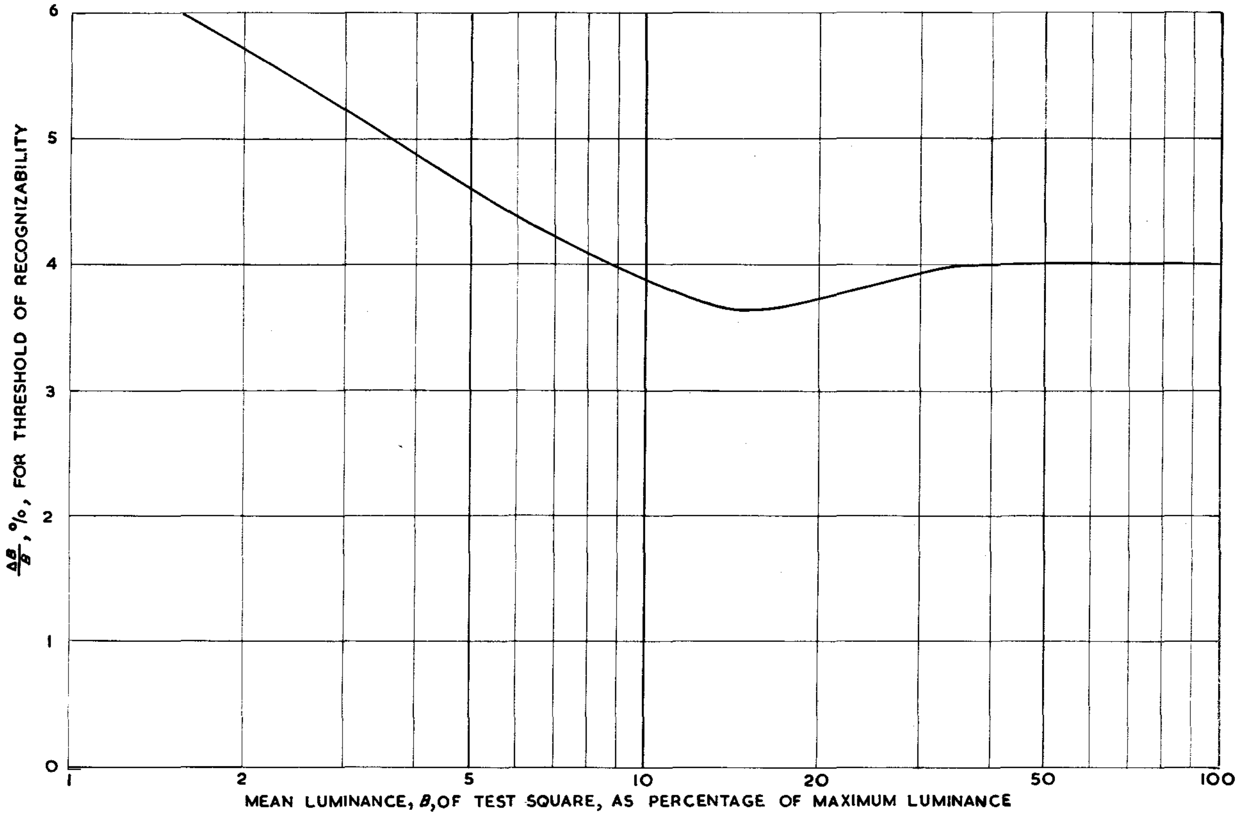

Fig. 2 - Fractional luminance-differences necessary for recognition of superimposed numerals

experiments were repeated (with a smaller number of observers) with the peak luminance adjusted to 10 ft-L (108 asb) and all other luminance levels, including that of the ambient lighting, set to approximately half the values shown in Table 1. The results of these tests, when plotted against normalized luminance, were virtually identical with those for the original tests.

Some extra measurements were made with the monitor adjusted so that the darkest square had a luminance three times that used for the main series of measurements, in order that results could be obtained for a luminance between 0·3 and 3 ft-L (3·2 and 32 asb).

In order to measure the effect of random noise in masking the luminance discontinuities, the tests were repeated with noise added to the signal at the monitor input. The noise was obtained from a high quality vestigial-sideband television receiver fed with unmodulated carrier; the noise magnitude was adjusted to an r.m.s. level 27 dB below the maximum (black-to-white) picture signal produced by the test card. The effect of adding noise was to increase the fractional luminance-difference required for 50 per cent recognition by a factor of about 1·7, without materially altering the shape of the curve.

The criterion of 50 per cent recognizability of the numerals forms a reasonable basis for determining the optimum spacing of luminance levels in a quantized display.

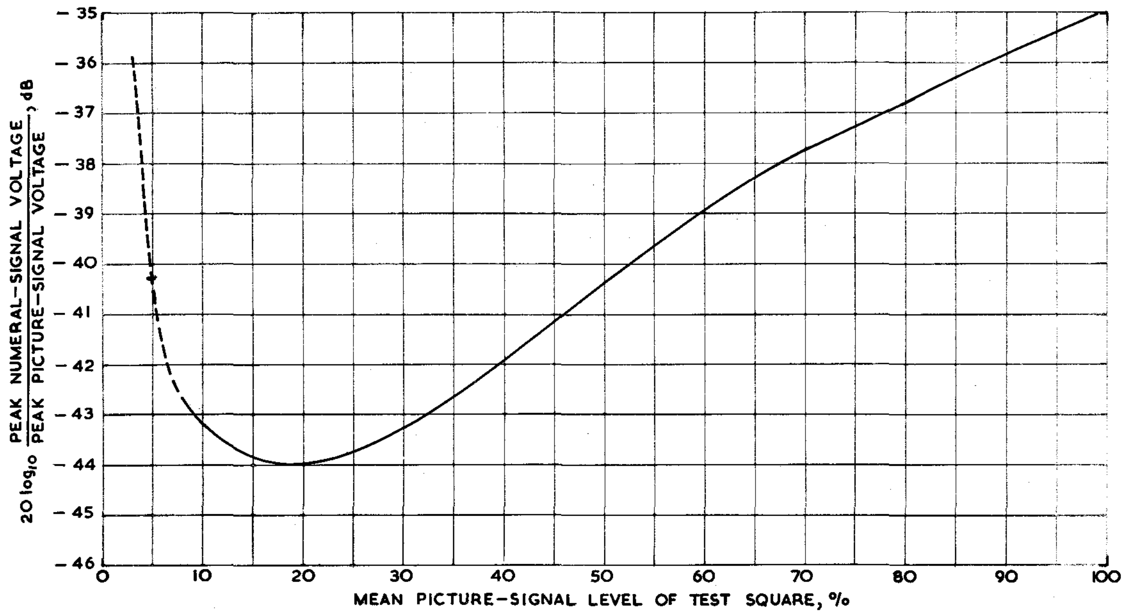

Fig. 3 - Signal conditions necessary for recognition of superimposed numerals

In Fig. 3, the relationship shown in Fig. 2 has been expressed in terms of variables referring directly to quantities that would be measured by means of a waveform monitor; the ordinates represent ratios of numeral-signal magnitude to maximum picture signal (black-to-white) and the abscissae represent the values of picture-signal level upon which the numeral signals were superimposed.*

It will be seen that the magnitude of the numeral signal, and hence the spacing of quantum levels, varies over a range of 9 dB. The total number of quantum levels defined by this relationship is about 95, this figure falling to 56 when the results obtained in the presence of noise are used.

2.2. Extension of the Investigation to Other Forms of Perturbing Signal

Fig. 2 shows that the threshold fractional luminance-difference is virtually constant over the greater part of the grey scale. As previously mentioned, the visibility of random noise added at the input to the display tube has been stated to be virtually independent of the grey level against which it is seen; this corresponds to a horizontal line on Fig. 3. The experiments now to be described were initiated in order to investigate this obvious discrepancy.

Fig. 4 shows a typical display used in these experiments. It consists of a normal test card into which two comparatively small test areas have been electronically inlaid.

* In order to permit comparison with the results of later experiments Fig. 3 has been derived from Fig. 2 by means of the luminance/voltage characteristic of the monitor used in the later experiments and not that of the monitor actually used in the experiments with numerals.

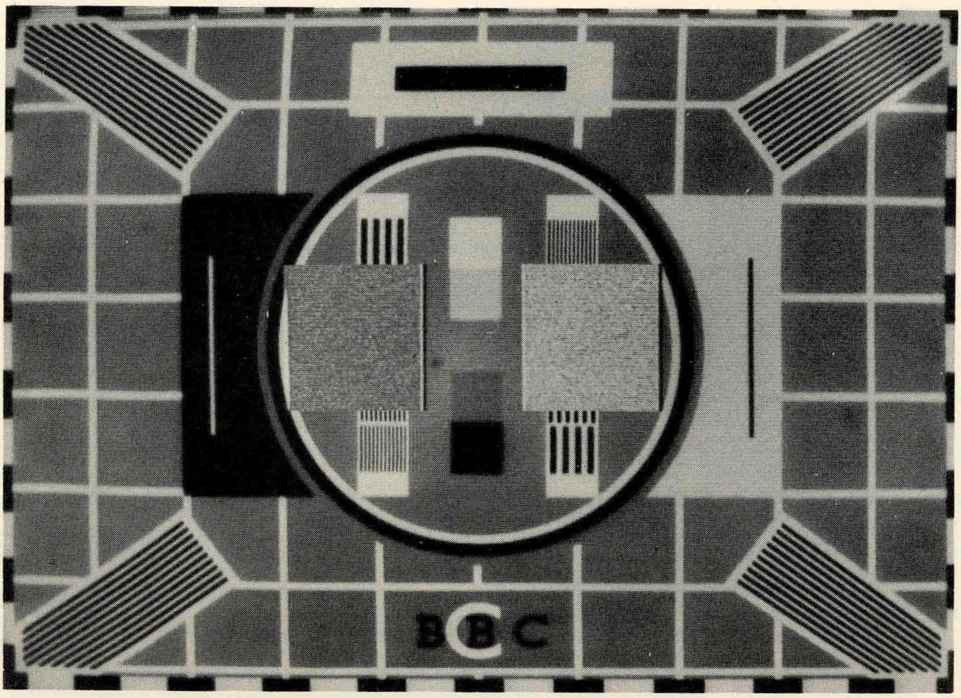

Fig. 4 - Test Card with random noise inlaid

The test procedure will be described for the case illustrated in Fig. 4 in which random noise was displayed in both squares. One of the team of seven observers who took part in the tests sat in front of a 21 in (53 cm) monitor, at a distance from the screen equal to five times the height of the displayed picture. The engineer supervising the test could control the mean picture-signal level of each square test-area and also the magnitude of the noise displayed in the left-hand square. An attenuator controlling the magnitude of the noise displayed in the right-hand square was operated by the observer, whose task was to adjust this attenuator until he judged the noise to be equally visible in the two squares.

Throughout the test the mean picture-signal level within the left-hand square was maintained at 45 per cent, corresponding to 20 per cent of peak luminance, and the superimposed noise was maintained at a predetermined magnitude. The mean picture-signal level of the right-hand square was successively set to a number of values, and for each value the observer adjusted his attenuator, taking his own time to do so; the attenuator setting was then recorded by the supervising engineer. High and low values of picture-signal level were presented in a random sequence in order to minimize any tendency for the observer to be influenced by his previous decisions. Each test included a control comparison in which the mean picture-signal level was the same for the two squares, thus providing a check of equipment calibration. As in the experiments already described, the contrast range of the display was eighty to one, bounded by luminances of 20 ft-L (210 asb) and 0·25 ft-L (2·7 asb), and the bandwidth of all superimposed test signals was restricted to 3 Mc/s.

Four perturbing signals were used for the initial set of experiments, and these signals will now be described. The reference level quoted for each signal is that of the comparison signal displayed in the left-hand test-square at a mean picture-

signal level of 45 per cent; this level is expressed in decibels relative to the peak (black-to-white) picture-signal voltage, and denotes the r.m.s. voltage for noise and the peak-to-peak voltage for repetitive waveforms. All test signals displayed in the left-hand test square were of similar visibility.

The four signals were:

(a) Random noise having a uniform spectrum (reference level: −34 dB).

This was the output from a noise generator utilizing an illuminated photomultiplier as its noise-generating element and designed to produce an output having a uniform energy-spectrum over a range of frequencies extending from 100 kc/s to higher than 3 Mc/s.

(b) Random noise having a triangular spectrum (reference level: −28 dB).

This was derived from uniform-spectrum noise by passing it through a circuit having a gain that was proportional to frequency.

(c) A signal producing a broad stationary pattern (reference level: −39 dB).

This was a square wave, having a fundamental frequency of about 250 kc/s locked to the line-scanning frequency. The pattern therefore took the form of alternate dark and light vertical bars, and it was arranged that two dark and three light bars were symmetrically disposed within each test square.

(d) A signal producing a fine stationary pattern (reference level: −31 dB).

This was a 2 Mc/s sine-wave, locked to the line-scanning frequency; each test square contained about 20 cycles of the resultant pattern of vertical stripes.

The results of the tests using these signals are shown in curves (a) and (b) of Fig. 5. This figure shows, for a number of types of superimposed signal, the relationship between the fractional luminance-difference ($\Delta B/B$) for constant visibility and the mean test-square luminance. The vertical scales of the curves have been chosen so as to show up similarities and differences in their shapes. The single curve (a), describes the results obtained with both forms of random noise, and curve (b) refers to both stationary patterns; the approximations involved introduce a maximum error of 1 dB and a mean error of about ½ dB. It will be seen that there is a considerable difference between curves (a) and (b), and this difference is much more than is attributable to the statistical spread of the measurements; the standard deviation of the results using seven observers was typically 1 dB, increasing to about 1½ dB at low values of luminance.

Further tests were therefore devised in an attempt to discover the reason for this difference.

Random-noise waveforms are characterized by crest factors higher than those of sine waves and square waves, and, in order to establish whether this was significant, the waveform of flat-spectrum noise was subjected to peak clipping, its crest

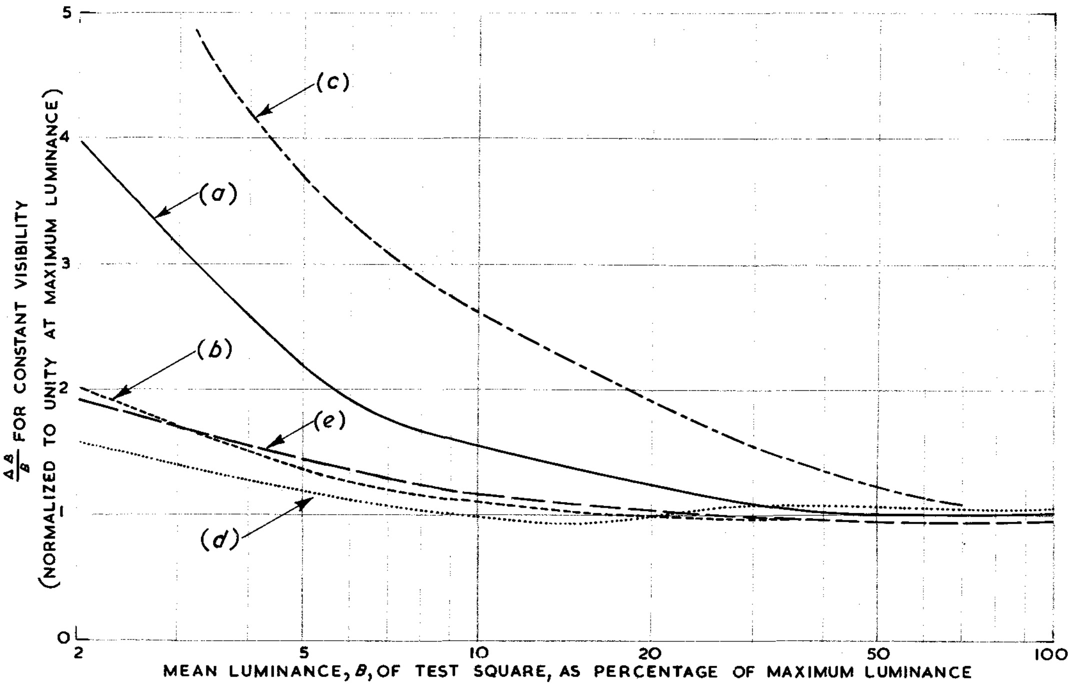

Fig. 5 - Fractional luminance-differences for constant visibility, as functions of test-square luminance

(*a*) Random noise, or pattern having low coherence between successive displays

(*b*) Stationary patterns

(*c*) Pattern displayed in alternate polarities

(*d*) Numerals

(*e*) Stationary pattern (from Hecht, Peskin and Patt)

factor thereby being reduced from 12 dB to 6 dB. When the resulting waveform was displayed, its visibility was found to vary with luminance in exactly the same way as the visibility of the unclipped waveform. Thus it may be concluded that the value of the crest factor is not significant in this connection.

The next perturbing pattern to be used was spatially incoherent, but stationary; this "frozen noise" pattern was produced by scanning an enlargement of photographic grain. When visibility measurements were made, using this pattern, the results defined a curve that lay between curves (a) and (b) of Fig. 5 but was decidedly closer to curve (b), thus suggesting that the observed behaviour of random noise was in some way connected with the incoherence between the noise patterns generated during successive picture periods. Because of this incoherence, partial cancellation occurs when random-noise patterns are integrated over two or more field periods. Consequently, when a photograph is taken from a television screen displaying a noisy picture, the degree of noisiness visible in the photograph decreases as the exposure time is increased. Owing to the retentivity of the eye, partial cancellation of luminance fluctuations must also take place in the eye of an observer looking at a noisy television picture, and the greatest reduction in visibility may be expected to occur at low values of luminance, at which retentivity is known to be greater.

This mechanism, therefore, could account for the observed difference between the visibility of patterns and that of noise. A further perturbing signal was devised in order to establish whether the effect was of the correct magnitude. This signal consisted of the output of a 1 Mc/s oscillator whose frequency fluctuated to the very slight extent necessary in order to produce low coherence between the patterns displayed during successive field periods. These patterns, therefore, although individually coherent, were nevertheless as likely to cancel as to reinforce one another during successive fields. One would therefore expect visual retentivity to influence their visibility and the visibility of random noise similarly. When the visibility of the display produced by this perturbing signal was measured at different values of luminance, the results did in fact define a curve whose shape was identical to that of the random noise curve (a) in Fig. 5.

Another perturbing signal was designed to allow the influence of visual retentivity to be measured at its maximum effectiveness. The frequency of an oscillator, nominally 1 Mc/s, was maintained so as to differ, by the picture frequency, from a multiple of line-scanning frequency. This frequency relationship is one of a number that are of especial interest in connection with co-channel interference, and are generally described by the term "precision offset, best". In the resultant display of vertical stripes, dark stripes in one field coincided with light stripes in the next, and, over a period of two fields, substantial cancellation took place. The cancellation was incomplete, first because interlaced rasters are not spatially coincident, and secondly because the non-linear voltage/luminance characteristic of the display tube produced a pattern of vertical bars having twice the fundamental frequency of the two cancelling patterns. Curve (c) of Fig. 5 shows how $\Delta B/B$ varied with the mean test-square luminance when the visibility of the test pattern was maintained constant. It will be seen that, as would be expected, this quantity increases at low values of luminance to a greater extent than was observed in the case of noise.

Three other forms of perturbing signal used during the course of the investigation are worthy of brief mention, because they confirm the correctness of classifying signals according to whether or not cancellation can occur between successive presentations. A coherent, fairly fine pattern was subjected to an oscillating movement slow enough to be easily followed by the eye; the relationship between $\Delta B/B$ for constant visibility and the mean luminance of the test square was found to be of the same form as for a stationary pattern. This relationship was also found to apply when the intensity of a stationary pattern was sinusoidally modulated at a few cycles per second, producing a display that flickered but did not exhibit cancellation between successive presentations. Similarly, random noise having an upper frequency limit of about 300 kc/s was found to behave, in this respect, in the same way as random noise having a spectrum uniform to 3 Mc/s.

3. DISCUSSION OF RESULTS

The results of the measurements made with stationary, coherent perturbing patterns should agree with those obtained in the experiments concerning the recognizability of numerals, described earlier. The results of these "numeral" experiments are shown as curve (d) of Fig. 5, which is considered to be in fair agreement with curve (b); in view of the limited accuracy of the experiments involving numerals, neither the dip in the value of $\Delta B/B$ at intermediate values of luminance nor the consistent separation of the curves at low luminance is considered significant.

The visibility of a low-contrast pattern as a function of its mean luminance has been investigated by a number of workers in the field of physiological optics. Close agreement between their results and ours is not to be expected, because there are considerable differences between the respective observation conditions, but a comparison has been made between the results of our own experiments and those of one of the more relevant optical investigations, in order to confirm that there are no gross discrepancies.

Hecht, Peskin and Patt[1] measured the fractional luminance-difference for threshold visibility as a function of the mean retinal illumination over the area corresponding to the test field; they maintained a constant pupillary aperture by means of an artificial pupil. In order to express their results in a form allowing comparison with our own, we have assumed that the observers in our experiments likewise maintained a constant pupillary aperture as they compared the two small test areas; their retinal illumination would thus be directly proportional to the luminance of the area under observation, the factor of proportionability being dependent upon the value of pupillary aperture assumed. We have in fact assumed the value of this aperture to be that producing the closest agreement between curve (b) of Fig. 5 and the results of Hecht, Peskin and Patt. By means of this procedure these results were converted to the form shown in curve (e) of Fig. 5; this corresponds to a pupillary diameter, for our observers, of 4 mm. This is a highly credible value; a published relationship[5] between pupillary diameter and field luminance shows this diameter as corresponding to a field brightness of 4 ft-L (43 asb), which was in fact the value of brightness over the greater part of the test card within which the test areas were inlaid. Thus the results of the two investigations may be seen to be substantially in agreement, notwithstanding the very different experimental conditions.

In Fig. 6 the information contained in curves (a), (b) and (c) of Fig. 5 is expressed in terms of variables referring directly to quantities that would be measured by means of a waveform monitor. The ordinates are proportional to perturbing-signal magnitude for constant visibility, and the abscissae are the associated values of mean test-square picture-signal level. The relative positions of the curves have been arbitrarily chosen so as to make them coincide at the maximum value of the abscissa. The curve for triangular-spectrum noise may be seen to rise less steeply than that for uniform-spectrum noise, at the lower end of the grey scale. This is probably because of the large voltage excursions that occur in the triangular-spectrum noise waveform; the increase in visibility that applies to excursions lying well above the mean picture-signal level of the test square more than outweighs the decrease in the visibility of excursions lying well below this level. It will be seen that, for the particular viewing conditions used, the voltage required for constant visibility of random noise varies by only about ± 2 dB over the greater part of the grey scale. Thus there is no great contradiction between the results of this investigation and the statement, quoted earlier, that equal excursions of noise voltage produce equal subjective visibility at all grey levels. It would, however, be impermissible to extend such a statement to the visibility of coherent patterns, where the voltage for constant visibility varies by ± 4 dB. It might, in fact, be possible in some instances to secure a useful reduction in the visibility of coherent interference by suitably modifying the contrast law of the video waveform prior to the point in the television chain at which the interference occurs. In this way the final, displayed picture could be made to exhibit an equally visible level of interference at all parts of the grey scale which might be subjectively preferable to more intense interference largely confined to dark grey areas.

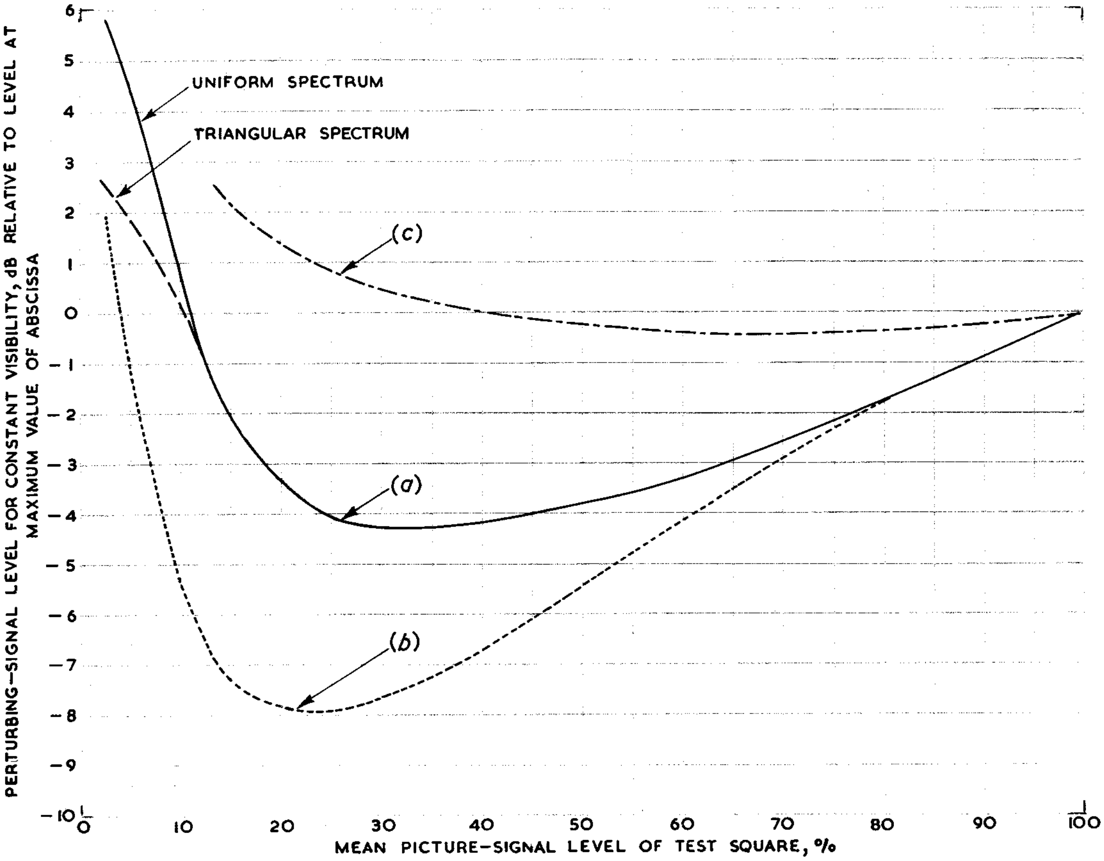

Fig. 6 - Perturbing-signal levels for constant visibility

(*a*) Random noise or pattern having low coherence between successive displays

(*b*) Stationary patterns

(*c*) Pattern displayed in alternate polarities

The actual levels of the various perturbing signals used in this investigation are shown in terms of $\Delta B/B$ in Fig. 7 and in terms of voltage ratios in Fig. 8.

3.1. The Implication of the Results Concerning the Visibility of Noise as a Function of its Bandwidth

It is well known that the visibility of flicker depends not only on the frequency, waveform and magnitude of the luminance fluctuation, and the mean luminance about which it occurs, but also upon the angle subtended at the observer's eye by the flickering object; other things being equal, the smaller the angle subtended, the less noticeable is the flicker. The effective visual integration of television noise is therefore likely to be affected by the size of the granular structure of the noise, which in turn is inversely related to the bandwidth of the noise.

Mertz[6] reports Baldwin as having observed experimentally that when the bandwidth of uniform-spectrum noise is increased to include higher frequencies, the visibility of the noise is not increased, despite the increased intensity of the

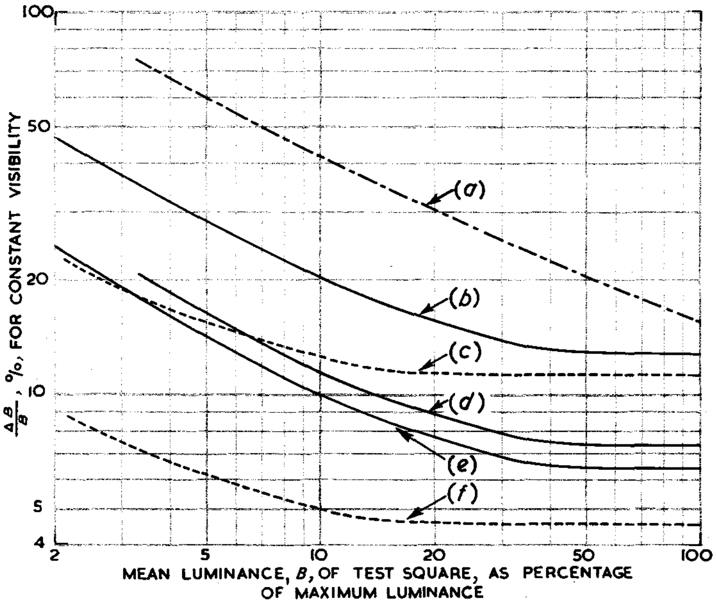

Fig. 7 - Magnitudes of fractional luminance-differences caused by various perturbing signals

(*a*) Pattern displayed in alternate polarities
(*b*) Random noise (triangular spectrum)
(*c*) Stationary pattern (fine)
(*d*) Pattern (fairly fine) having low coherence between successive displays
(*e*) Random noise (uniform spectrum)
(*f*) Stationary pattern (broad)

individual noise perturbations. It seems reasonable to assume that this is because the increased intensity of the noise perturbations is offset by their smaller size. They are less visible than larger perturbations of the same intensity both because they are closer to the limit of visual acuity and because their apparent intensity is more effectively reduced by integration. In order to relate the effectiveness of visual integration to the size of the displayed patterns, comparisons were made, for three sizes of pattern, between the respective visibilities of a "precision-offset-best" pattern of the type already described, and the pattern of stationary vertical bars produced when the interfering oscillator frequency was changed by 25 c/s so as to be a multiple of line-scanning frequency. The quantity measured at various parts of the grey scale was the decrease in perturbing signal level necessary to maintain constant visibility when a change was made from the first of these patterns to the second. This quantity, which will be referred to as the "advantage" of the "precision-offset-best" relationship, is shown, in decibels, in Fig. 9 for the three pattern sizes corresponding to nominal frequencies of 400 kc/s, 800 kc/s, and 2·5 Mc/s.

It will be seen that, for the larger patterns, the advantage decreases considerably at high values of picture-signal level. This is because the luminance is then too high to allow flicker "fusion" of consecutive fields.

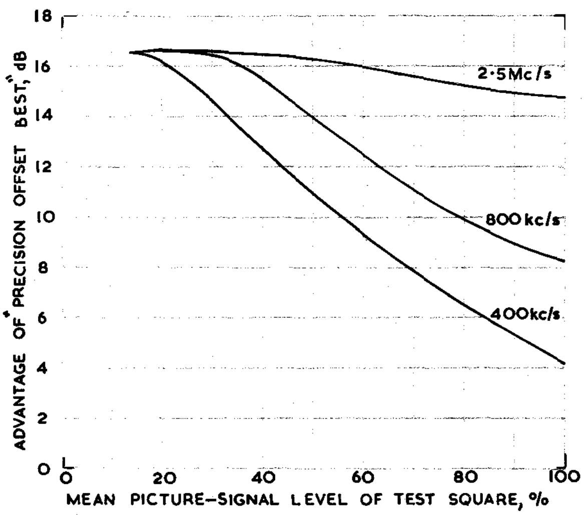

Fig. 9 - Dependence of precision-offset advantage upon pattern size

It should perhaps be emphasized that this investigation was confined to pictures scanned on the 405-line British standard, which has a field rate of fifty per second. Use of the 525-line American standard, which has a field rate of sixty per second, would be expected to lead to different results for all those forms of superimposed signal whose visibility is affected by visual retentivity.

4. CONCLUSIONS

The visibility of small luminance perturbations in television displays has been found to vary with the luminance of the test square in a manner that is markedly different according to whether the perturbations are the result of a coherent pattern or of random noise.

When coherent patterns are displayed, the relationship between their visibility and their mean luminance has been found to be in good agreement with the results of optical observations. The visibility of random noise, however, exhibits a relatively greater decline at low levels of luminance where, as a result of increased retentivity, the eye achieves more effective cancellation between the mutually incoherent patterns presented to it during successive field-scanning periods.

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Printed by B.B.C. Research Department, Kingswood Warren, Tadworth, Surrey